

A Curriculum-Linked Professional Development Approach to Support Teachers' Adoption of Web GIS Tectonics Investigations

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Abstract

A curriculum-linked professional development approach designed to support middle level science teachers' understandings about tectonics and geospatial pedagogical content knowledge was developed. This approach takes into account limited face-to-face professional development time and instead provides pedagogical support within the design of a Web-based curriculum with extensive teacher support materials. This paper illustrates how curriculum design can provide teachers with supports for content (e.g., tectonics) and geospatial instruction with Web GIS. The effectiveness of the approach is presented with a focus on how the curriculum implementation of the Web GIS tectonics investigations and the curriculum support materials provided teachers with the professional growth required for successful curriculum implementation.

In the study of the Earth and environmental sciences, the data pertinent to any question must be geospatially referenced to be meaningful. The ability to explore interrelationships amongst and within data sets requires data manipulation while preserving geospatial relationships. These analyses are most effectively done with a geographic information system (GIS) and necessitate geospatial thinking and reasoning skills.

Geospatial thinking and reasoning is a cognitive process that enables learners to extract useful information from spatial (two- or three-dimensional) representations of reality. In the context of Earth science, it typically involves geospatial analysis and interpretation of maps, models, diagrams, and charts, and simultaneous analysis and interpretation of multiple data sets.

Recent research by teams of learning scientists confirms that spatial ability, measured by visualization and reasoning tasks, is a significant factor in STEM subject achievement (Lubinski, 2010; Wai, Lubinsky, & Benbow, 2009). For many concerned with widening access to and involvement in the sciences, these findings are significant, especially since research has confirmed that gender plays a role in some spatial abilities (Voyer, Voyer, & Bryden, 1995).

Calls have followed for explicit attention to improving spatial thinking skills in girls, including explaining that spatial skills are not innate but can be developed (National Research Council, 2006); encouraging young people to engage in learning activities that use spatial thinking skills (Hill, Corbett, & St. Rose, 2010); and using geospatial visualizations, tools, and representations to promote critical thinking, analysis, and reasoning to address problem solving (U.S. Department of Labor, Employment & Training Administration, 2010). A recent meta-analysis conducted by Utall et al. (2013) concluded that spatially enriched curricula succeeds in increasing STEM performance and participation.

The use of GIS to investigate the Earth and environmental sciences spatially during classroom investigations has proved effective in the development of accurate scientific understandings about complex Earth and environmental science concepts with secondary learners (Bednarz, 2004; Bodzin & Fu, 2014; Bodzin, Fu, Kulo, & Pfeffer, 2014; Edelson, Pitts, Salierno, & Sherin, 2006; Kulo & Bodzin, 2013; NRC, 2006). However, geospatial thinking and reasoning are not widely addressed in science education curricula (Black, 2005; Mathewson, 1999; Wai et al., 2009). Therefore, development and implementation of curriculum to better enable the application of geospatial thinking and reasoning in science education are needed (Baker, Palmer, & Kerski, 2009; Bodzin, 2011). Additional studies are needed to understand which types of pedagogical implementation supports may help teachers more effectively implement successful pedagogical approaches to promote student geospatial thinking skills (Baker et al., 2015).

Effectively teaching about geoscience topics that are geospatial in nature requires specific technological pedagogical content knowledge (Mishra & Koehler, 2006) and implementation supports to incorporate geospatial technologies into the classroom. GIS is a geospatial technology that can be used to promote geospatial thinking through the analysis of geo-referenced data and imagery.

Teaching science with geospatial technologies involves geospatial science pedagogical content knowledge, a specific type of technological pedagogical content knowledge. Science teachers with geospatial science pedagogical content knowledge have a more complete understanding of the complex interplay between science pedagogical content knowledge and geospatial pedagogical content knowledge and can teach science using appropriate pedagogical methods and geospatial technologies (Bodzin, Pfeffer, & Kulo, 2012).

This knowledge involves understanding how to model geospatial data exploration and analysis techniques and how to scaffold students' geospatial thinking and analysis skills effectively. The idea of geospatial pedagogical content knowledge transcends content disciplinary boundaries, since geospatial technology can interact with other discipline-

based pedagogical content (for example, geography and history) in ways that may produce effective teaching and student learning opportunities.

Unfortunately, many teachers have not had professional development experiences that foster sufficient geospatial pedagogical content knowledge to implement Earth and environmental science curriculum using geospatial technologies to promote both Earth science learning and the development of geospatial thinking skills. In some U.S. school districts, the available time within a school year to provide in-service science teachers with high-quality, face-to-face professional development to adopt new science education technology-integrated curriculum is limited.

In recent years, we have partnered with an urban school district in a systemic middle level science curriculum reform effort. During this time, school financial resources were extremely limited, and science teachers were allowed to attend only 2 or 3 days of face-to-face professional development during the school year. To address this common reality, we developed and implemented an approach to promote teachers' professional growth with curriculum-linked professional development supports within the Web-based curriculum.

In this paper we describe a curriculum-linked professional development approach designed to support middle level teachers' understandings about tectonics in addition to supporting their development of geospatial pedagogical content knowledge to teach with a Web GIS. The approach takes into account limited face-to-face professional development time and, instead, provides substantial pedagogical support within the design of Web-based curriculum and teacher support materials.

We illustrate the effectiveness of the curriculum materials to simultaneously provide supports for both content and Web-based teaching with geospatial technologies. The effectiveness of the curriculum-linked professional development approach is presented with a focus on how the curriculum enactment of the Web GIS tectonics investigations and the curriculum support materials provided teachers with professional growth.

Designing Curriculum Materials to Support Teachers

Curriculum materials can be designed to incorporate professional development opportunities for teachers to assist them with deepening their understandings of science content, in addition to accomplishing instructional goals for their students. This professional development may influence teacher decision-making by conveying instructional practices, providing appropriate science content materials, or providing pedagogical implementation ideas (Davis & Krajcik, 2005; Davis & Varma, 2008). Curriculum designers can develop learning materials that better accommodate instruction by moving away from a one-size-fits-all-students instructional model and, instead, providing for flexible adaptations to instructional implementation. Such curriculum designs can provide for different modes of instruction that are important given the diverse nature of students and their abilities in science classrooms.

When curriculum materials are expected to take on the role of change agent and transform teacher practice—as in a systemic reform initiative—the challenges of effective implementation are heightened. Unfortunately, research has shown that teachers face many obstacles when they attempt to use curriculum materials that are based on an instructional approach to teaching and learning that differs from their own experiences (Stein, Grover, & Henningsen, 1996). When teachers enact instructional materials that utilize geospatial technologies to support inquiry-based learning environments, studies

have shown that they may experience technical issues pertaining to the interface design of software, have time constraints to learn how to use geospatial technologies software applications to teach students effectively, undergo difficulty with integrating the learning materials into their own school curriculum, and lack pedagogical content knowledge conducive to teaching with geospatial technologies in classroom settings (Baker & Bednarz, 2003; Patterson, Reeve, & Page, 2003; Trautmann & MaKinster, 2010).

One way of addressing these challenges is to design the curriculum materials to promote the pedagogical design capacity of teachers—that is, their ability to perceive and mobilize curriculum materials and resources for effective instructional enactment (Brown, 2009). The concept of pedagogical design capacity means that curriculum materials can be designed in ways to facilitate productive use by teachers to accomplish learning goals. Embedded supports must be included within the curriculum in the form of educative materials—features of curriculum materials designed to support teacher pedagogical content knowledge in addition to student learning (Davis & Krajcik, 2005).

Educative curriculum materials have the potential to support teacher learning in a variety of ways. For example, they may help teachers learn how to anticipate and interpret what learners may think about or do in response to instructional activities (Remillard, 2000). They may also support teachers' learning of subject matter (Schneider & Krajcik, 2002; Wang & Paine, 2003).

Educative curriculum materials can also include pedagogical implementation supports provided in the materials to engage teachers in the ideas underlying curriculum developers' decisions (Davis & Krajcik, 2005; Remillard, 2000). In these ways, educative curriculum materials can promote teachers' pedagogical design capacity, or their ability to use instructional resources and the supports embedded in curriculum materials to adapt curriculum to achieve productive instructional ends (Brown, 2009).

The Geospatial Curriculum Approach

Our curriculum approach for geospatial thinking and reasoning (Figure 1) builds on our previous geospatial curriculum design work (Bodzin et al., 2012; Bodzin, Anastasio, & Sahagian, 2015) and the National Science Foundation's Geotech Center's Geospatial Technology Competency Model (U.S. Department of Labor, 2010). The curriculum approach incorporates design principles in each investigation to promote geospatial thinking and reasoning skills, including the following:

1. Use motivating contexts and personally relevant and meaningful examples to engage learners.
2. Design image representations that illustrate visual aspects of Earth and environmental scientific knowledge.
3. Design Web GIS data to make geospatial relations readily apparent.
4. Scaffold students (Jonassen, 1999; Quintana et al., 2004) to analyze geospatial relations.
5. Develop curriculum materials to better accommodate the learning needs of all students, while also expanding the geospatial science pedagogical content knowledge in middle level teachers.

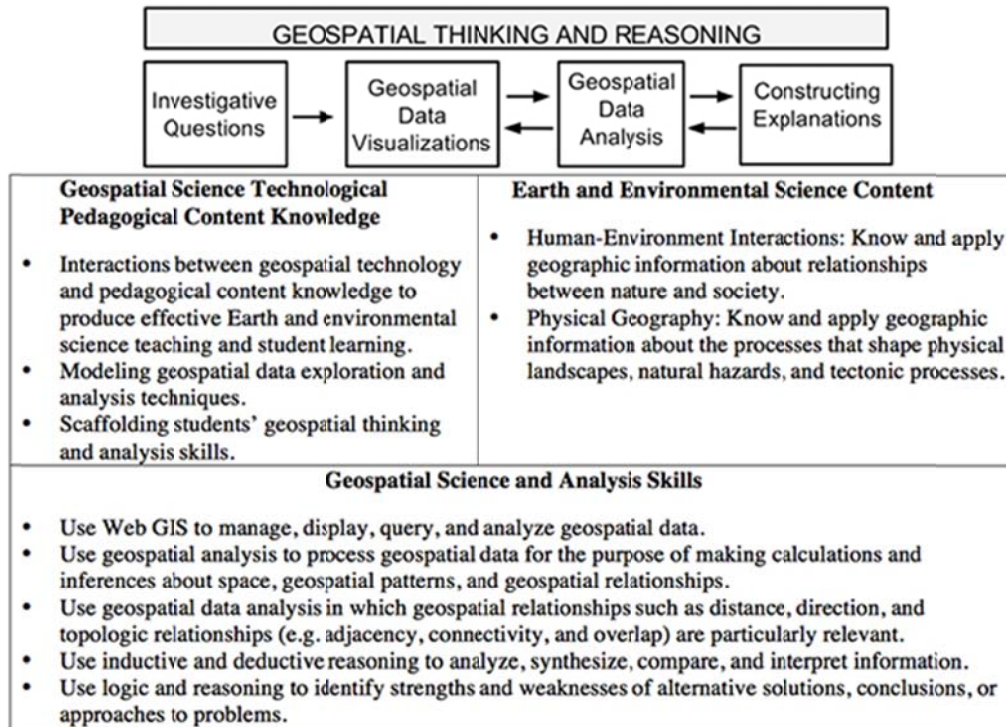


Figure 1. Key components of the geospatial curriculum design approach.

A primary goal of the curriculum approach is to develop geospatial learning activities in such a way that the software and hardware become transparent to the user. The initial geospatial data visualizations for each Web GIS investigation are designed to be quick and intuitive for both students and teachers to use, thus decreasing interface issues that were reported by users of other GIS platforms (Baker & Bednarz, 2003; Bednarz, 2004). The learning activities include educative materials (Davis & Krajcik, 2005) that use Web-based videos, text, and graphics to promote and support teachers' learning of important Earth and environmental science subject matter and geospatial science pedagogical content knowledge that they may require.

Each learning activity includes baseline instructional guidance for teachers and provides implementation and adaptation guidance for teaching a variety of learners, including reluctant readers, English language learners, and students with disabilities. These implementation suggestions are the result of our curriculum implementation findings during prototype and pilot testing of the Web GIS investigations as part of a design partnership with lead science teachers in the school district.

A key part of the curriculum-linked professional development approach includes a hybrid form of professional development that uses a limited number of face-to-face sessions and Web-based curriculum support materials delivered over the Internet to promote teachers' geospatial science pedagogical content knowledge in addition to science content knowledge. Such online professional development approaches were found to provide effective teacher support for the adoption of new curriculum with geospatial technologies in science classrooms (e.g., see Fishman et al., 2013; McAuliffe & Lockwood, 2014; Moore, Haviland, Whitmer, & Brady, 2014) and can promote science teachers' pedagogical design capacity for effective instructional enactment (Bodzin et al., 2012).

This form of professional development offers teachers opportunities to learn science concepts with geospatial technologies over a longer time period as compared to typical summer institutes and makes possible working with teachers over larger geographic areas than would otherwise be feasible (Greenhow, Robelia, & Hughes, 2009). The curriculum materials are designed to convey instructional practices, provide appropriate science content materials, and provide pedagogical implementation ideas (Davis & Krajcik, 2005; Davis & Varma, 2008). Our professional development approach assumes that teachers are pedagogical experts capable of adapting curriculum materials to meet the needs of their students (as described in Penuel, Fishman, Yamaguchi, & Gallagher, 2007).

The curriculum includes a series of educative materials designed to support teacher implementation of the investigations including,

- *Instructional Framework.* This section provides teachers with an overview of the curriculum framework, design principles, and the instructional model for teaching with geospatial technologies. This section also presents science education standards alignment.
- *Teacher Guides.* Instructional guides designed to support a teacher's implementation of a specific learning activity. They include detailed information for viewing and analyzing geospatial data during the learning activities and also include implementation suggestions and ideas to adapt a learning activity for different types of learners.
- *Support Materials.* This section includes webpages that contain text, graphics, and animations designed to enhance a teacher's content knowledge about a particular tectonics topic that are unique to our Web GIS learning activities. The topics included reference frames, heat flow, geologic faults, gravity anomaly, and GPS geodesy. This section also includes tutorial videos that provide detailed overviews of each Web GIS learning activity with a focus on geospatial data analysis and understandings about the geospatial relationships within the data.
- *Instructional Sequence.* These webpages include a recommended implementation sequence for each investigation, implementation suggestions, and hypertext links to content supports and specific materials needed for the learning activities including the Web GIS, assessments, student investigation sheets and handouts, teacher guides, and Web GIS tutorial videos.

The curriculum's educative materials and embedded supports were designed to assist teacher development of both tectonics content knowledge and geospatial science pedagogical content knowledge for effective curriculum enactment. We developed these supports to address the need for just-in-time professional development experiences to help educate teachers about important tectonics concepts and to support their development of pedagogical content knowledge to teach with a novel Web GIS curriculum that promotes development of geospatial thinking skills.

Tectonics Web GIS Investigations

In partnership with an urban school district, we developed a series of six Web GIS tectonics investigations designed to augment the middle school Earth and environmental science curriculum. The investigations were developed using the curriculum design approach for geospatial thinking and reasoning (see Figure 1). They were designed for students to investigate important tectonics concepts that are more difficult to understand using a traditional text and worksheet-based medium.

The investigations were intended to promote geospatial thinking and reasoning skills as students analyzed, inferred, and evaluated georeferenced earthquakes, volcanoes, plate boundaries, heat flow, age of the ocean floor, and other data in the Web GIS to understand important concepts related to heat flow, plate movements, and the tectonic processes responsible for geologic hazards. The learning activities were purposefully designed for students to use geospatial analysis to examine geospatial patterns and relationships within the data.

The Web-based visualization and analysis tools were developed with Javascript APIs (application programming interfaces) to enhance the Web GIS interface. They are compatible with computers and mobile learning devices (such as iPads, other tablet devices, and smart phones) that are rapidly appearing in schools. The Web GIS interface integrates graphics, multimedia, and animations that allow users to explore and discover geospatial patterns that are not easily visible as static single maps. The Web GIS features include a swipe tool that enabled users to see underneath layers, query tools useful in exploration of earthquake and volcano data layers, a subduction profile tool, and an elevation profile tool that facilitates visualization between map and cross-sectional views, a suite of draw and label tools, a geolocation function, and interactive image dragging functionality. The Web GIS tool set enables learners to view, dynamically manipulate, and analyze rich data sets to make informed decisions about living in areas containing seismic hazards from active fault zones.

The tectonics investigations were aligned to Disciplinary Core Ideas: Earth and Space Science from the National Research Council's (2012) *Framework for K-12 Science Education* ESS2.B: Plate Tectonics and Large Scale System Interactions. Each Web GIS investigation was designed with eight instructional events based on instructional design learning theories (Black & McClintock, 1996; Collins & Stevens, 1983; Gagné, 1985; Jonassen, 1997, 1999):

1. Elicit prior understandings of lesson concepts.
2. Present authentic learning task.
3. Model learning task.
4. Provide worked example.
5. Perform learning task.
6. Scaffold learning task.
7. Elaborate task with additional questions.
8. Review activity concepts.

The tectonics investigations are available at <http://www.ei.lehigh.edu/eli/tectonics>

Following is a brief overview of four of the investigations. After each overview, select examples of how the curriculum support materials provided teachers with geospatial science pedagogical content knowledge are presented.

Investigation 1 - Geohazards and Me

In Investigation 1, students develop a personal connection to geologic hazards. They discover where the most recent earthquake occurred near their geographic location and where the nearest volcano is located using the location function available on most devices. They also investigate how geologic hazards are distributed around the globe and infer how these hazards are related to plate tectonics.

Figure 2 displays a tectonics content knowledge support about seismic hazards that is included in the teacher guide. The information presented helps teachers learn that geologists determine seismic hazards by studying the timing, location, and magnitude of past earthquake events and use this information to develop risk-assessment maps that communicate the potential for seismic hazards to occur in a particular area. The Web GIS image in Figure 2 shows the displayed seismic-hazard layer. The darker-green color in the seismic-hazard layer on the U.S. East Coast is associated with a lower seismic-hazard risk. The yellow, orange, and red colors displayed in the seismic-hazard layer, such as those on the West Coast, are associated with a higher seismic-hazard risk typical of plate boundary regions.



Step 5: Compare your findings to a seismic hazard map.

In this last step, students will learn how scientists communicate information about seismic hazards to the public and assess hazards in different locations. Geologists determine seismic hazards by studying the timing, location, and magnitude of past earthquake events. Using this information they develop risk assessment maps that communicate the potential for seismic hazards to occur in a particular area and the worst case scenario should the hazardous event occur.



- Click on the **Map Layers** tab in the toolbars menu.
- Instruct students to turn-off all layers and then activate the **Seismic Hazards** layer by clicking on the check box. Instruct students to click on the **Map Legend** tab in the toolbars menu. The colors on this map represent the intensity of forces caused by shaking during an earthquake. Bigger earthquakes cause more shaking, so a larger value means these areas are more at-risk for higher magnitude earthquakes to occur.

Figure 2. Section from Investigation 1 Teacher Guide explaining the Web GIS seismic hazard data and how it relates to earthquake data.

The teacher guide prompts teachers to display earthquakes and volcanoes on the Web GIS so they can observe a key geospatial relationship; the highest risk areas correspond to the locations of more volcanoes and earthquakes (Figure 3). Since understanding this geospatial relationship is important for completing the investigation, the Web GIS tutorial video also explicitly models this data relationship.

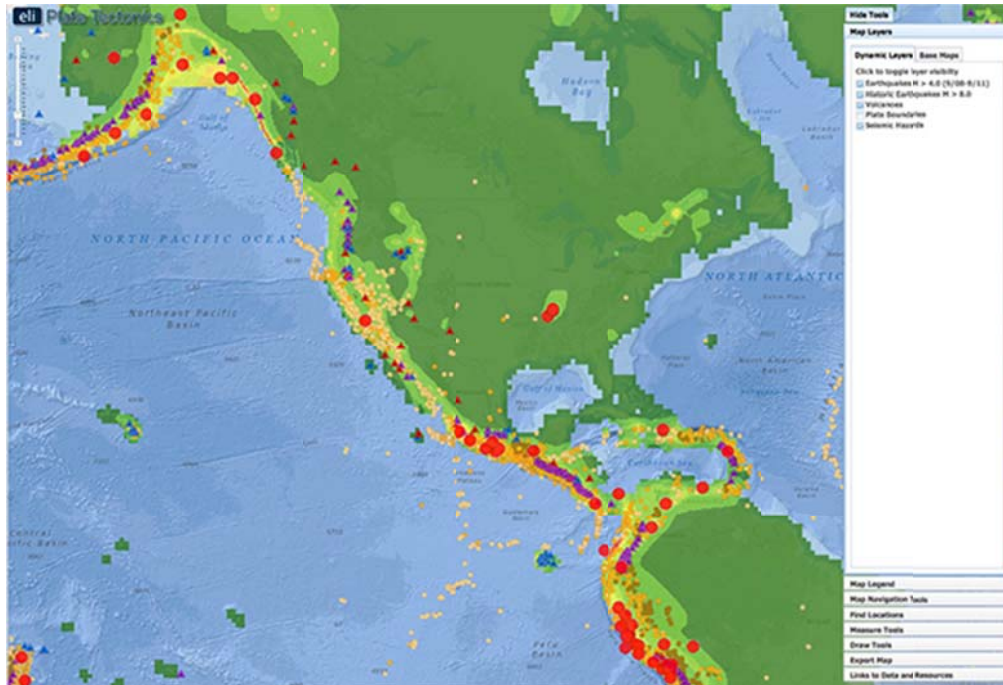


Figure 3. Web GIS display simultaneously showing earthquakes (circles), volcanoes (triangles), and seismic hazard layers.

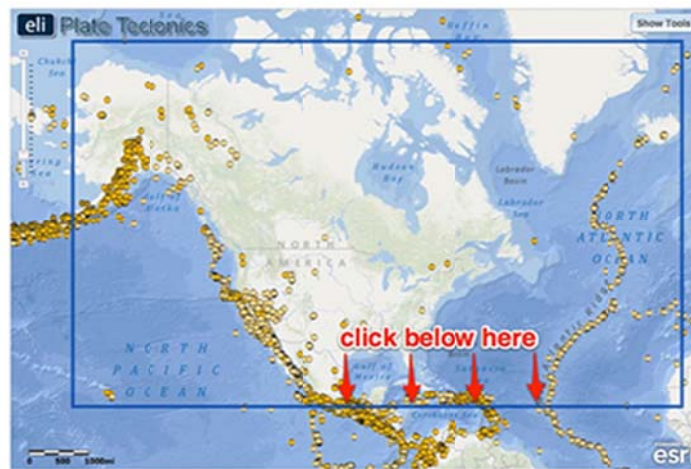
Investigation 2 - How Do We Recognize Plate Boundaries?

In Investigation 2, students use tectonics data to identify the eastern and western boundaries of the North American Plate. They analyze earthquake epicenter and volcano data to determine the boundaries of the North American Plate and analyze the movement of the surrounding plates to determine plate boundary types (divergent, convergent, or transform). As a part of this investigation's support materials, the teacher guide demonstrates methods for identification of plate boundary areas by locating earthquake epicenter clusters on the Web GIS (Figure 4). Explicit modeling of geospatial data exploration is provided in the teacher guide to show how to use the Web GIS to identify the adjacent plates next to the North American plate.

Investigation 3 - How Does Thermal Energy Move Around the Earth?

In Investigation 3, students locate areas where heat escapes from the Earth's interior. They investigate how surface heat flow (loss) is distributed around the Earth and its relationship to plate boundaries. They also explore the types of geologic features on the Earth's surface most commonly associated with heat loss. The Web GIS enables teachers to understand these complex ideas by analyzing georeferenced data sets. Teachers can dynamically visualize how heat flow on the Earth's surface is spatially related to lithosphere thickness, plate boundaries, and the age of the ocean floor using the swipe tool. Using the Web GIS data, they can observe that the highest surface heat flow is along divergent plate boundaries.

- d. Next, students will identify the name of the plates south of the North American plate by clicking different locations on their map where they think there are different plates. Make sure the class understands that earthquake epicenter clusters identify plate boundaries.



- e. Have students click on the **Map Layers** tab in the toolbox menu. Then, hide the toolbox menu so they can see the whole map.
- f. Instruct students to click different locations south of the North American plate, below the blue study box, where they think there may be a different plate. You may want to model this by clicking a location in the Caribbean Sea. This will pop-up a box that says "Caribbean Plate", and you can show students that earthquakes surround this plate. Have students click until they have identified the 3 different plates: Cocos, Caribbean, and South American. If needed, prompt students to click on South America to view a pop-up a box that says "South American Plate".

Figure 4. Investigation 2 teacher guide section that models a geospatial exploration technique.

Both the Web GIS tutorial video and the teacher guide explain how to use the swipe tool to discover the geospatial relationship between surface heat flow and the age of the ocean floor (see Figure 5). The surface heat flow layer displayed on the left side of Figure 5 reinforces the concept that oceans are hotter than continents. At the mid-ocean ridge near the figure's center, the correlation of heat flow and the age of the ocean floor is evident. Near the swipe seam, younger, hotter crust is apparent, whereas the older, colder oceanic crust is at the ocean's margins. On the right side of the figure, teachers can easily visualize the geospatial relationship that the age of the ocean floor increases as the floor moves continentward from the midocean ridge.

The Web GIS tutorial video and the teacher guide also models data exploration and analysis techniques for using the elevation-profile tool to discover that ocean bathymetry is related to both surface heat flow and the age of the ocean floor. The elevation-profile tool allows teachers to create an elevation profile in an area of the Web GIS map by drawing a line across that area (Figure 6). The elevation-profile tool simultaneously displays the elevation of a specific point on the map and that point in the corresponding map profile.

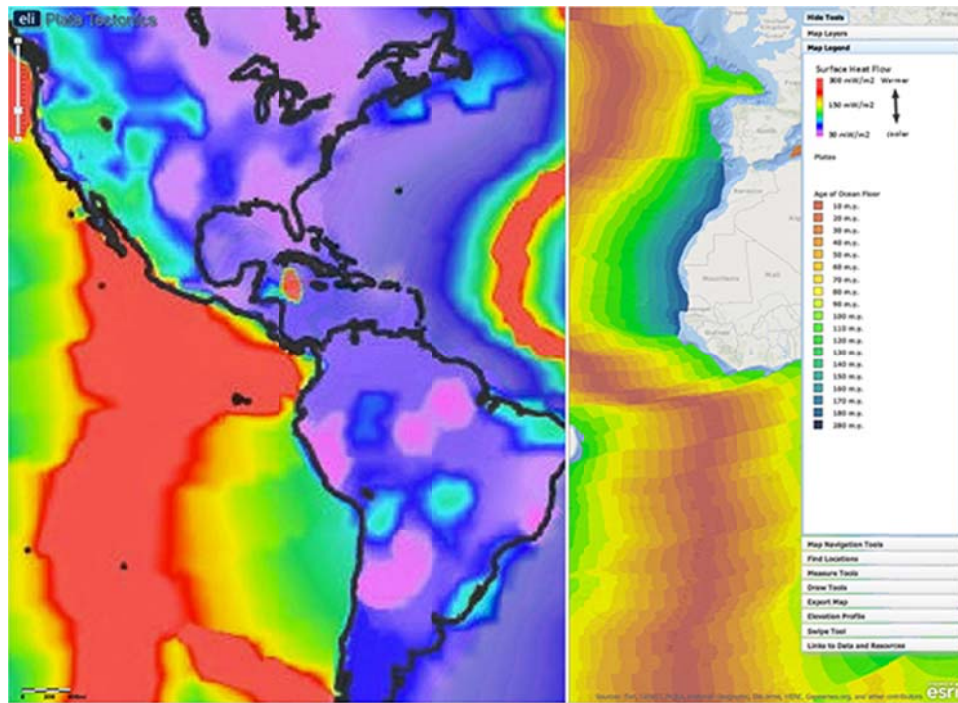


Figure 5. Web GIS image from Investigation 3 with swipe tool activated. The age of the ocean floor layer is displayed on the right of the white swipe seam. The surface heat flow layer is displayed on the left of the swipe seam.

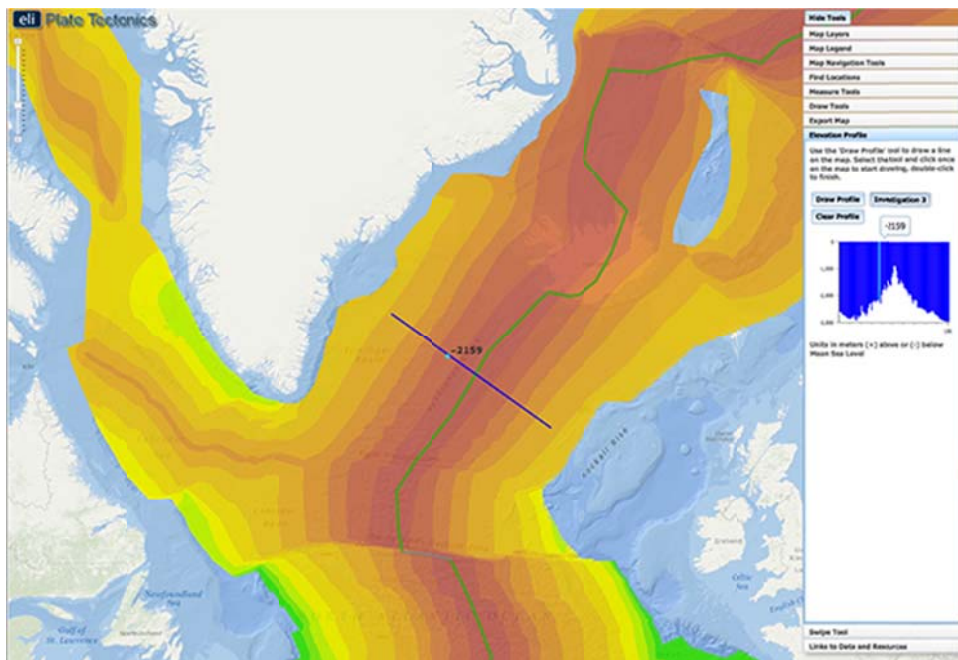


Figure 6. Web GIS image from Investigation 3 displaying the elevation profile tool. The age of the ocean floor layer is displayed.

In the investigation, the Web GIS helps make important geospatial relationships more easily evident. Younger ocean floor is warmer and, therefore, more buoyant and resides at higher elevations. As the ocean floor cools and spreads away from the divergent boundary, it sinks and decreases in elevation.

The instructional sequence webpage for Investigation 3 provides pedagogical implementation suggestions to assist teachers with using the Web GIS and its embedded tools to help students understand geospatial relationships (Figure 7). The implementation suggestions are designed to address difficulties that were observed with students during the prototype and pilot testing of the investigation. The instructional sequence webpage models data analysis techniques that are designed to help teachers work with their students to more readily observe geospatial patterns and relationships on the Earth's surface in addition to materials provided in the teacher guide.

9. Before students start Step 3, model the **Swipe Tool** and the **Elevation Profile**. First, using the Swipe Tool, show students how to activate the divider and click and drag to compare layers. Next, model how to interpret the Elevation Profile by showing how points on the profile graphic display correspond to locations on the Web GIS. Also, show your students how to draw a profile across the Mid-Atlantic Ridge.

Implementation suggestion: We recommend that you explicitly model how to interpret an elevation profile graph from a profile line drawn on the map.

Reading an Elevation Profile: All elevations below sea level will be negative numbers, while elevations above sea level will be positive numbers. Sea level is at 0 meters elevation. A deeper sea floor elevation corresponds to a higher negative number. A shallower sea floor elevation corresponds to a lower negative number.

A point on an elevation profile at - 3000 meters means that the elevation of the sea floor at that point is 3000 meters below sea level. Likewise, a point on an elevation profile at - 1000 meters means that the sea floor elevation at that point is 1000 meters below sea level. -3000 meters is deeper than -1000 meters.

Implementation Suggestion: Some students may require additional scaffolding to interpret the age of the ocean floor in the elevation profile display for item #7 on the Investigation Sheet. We suggest you start at the Mid-Atlantic Ridge to first identify the age of the ocean floor with your students. Next, note to students that the age of the ocean floor is symmetrical as it moves away from the Mid-Atlantic Ridge.

10. Review and discuss aloud student responses to key questions on their Investigation Sheets. Ask students if they have any questions about concepts covered in the lesson and respond to their questions.

Implementation suggestion:

For classes with students with special needs, you may wish to provide additional modeling, prompts and guidance as students work through the investigation. You may wish to explicitly model each procedural step with the Web GIS using a projected image before the students work independently or in pairs to complete the learning tasks.

11. If students at the completion of the activity do not understand that surface heat flow is greatest at divergent boundaries, and that age and elevation of the surface are related to heat flow, modify instruction as needed to ensure students understand these concepts.

12. To provide closure to this investigation, have students reflect on what they have learned about thermal energy in the Earth and discuss their responses. Here are some suggestions: Provide students with a reflective question to respond in their journals about tectonics. For example: Why do plate boundaries release more of the total thermal energy from the Earth than hotspots? What is the relationship between elevation, age, and surface heat flow?

Figure 7. Section from the instructional sequence webpage for Investigation 3.

Investigation 4 - What Happens When Plates Diverge?

In Investigation 4, students locate different divergent boundaries and study their history. They investigate how tectonic deformation is accommodated at plate boundaries when they examine earthquake and fault data and calculate the half-spreading rate of an ocean ridge. They also investigate features of passive margins, areas along coastlines where continental crust joins oceanic crust.

Understanding the Bouger gravity anomaly layer is important to this investigation, and it is a data layer that most middle-level science teachers are not familiar with. To ensure that teachers are provided with ample content support to understand and interpret this data layer, information is provided in multiple areas of the curriculum support materials, including the support materials section of the website, the Web GIS tutorial video, the instructional sequence webpage, and the teacher guide.

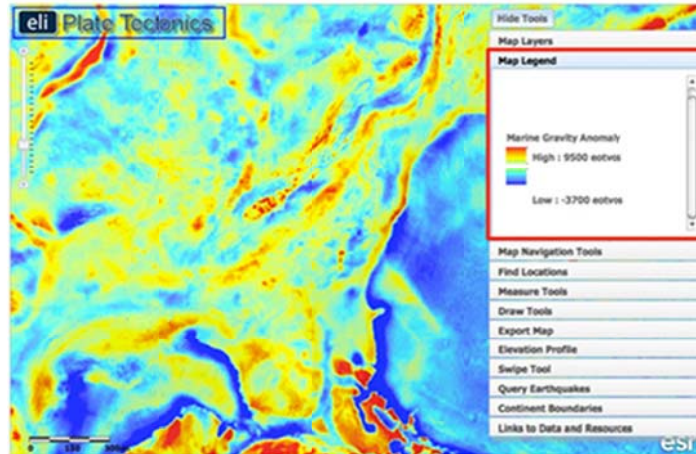
Providing important content and geospatial analysis techniques in multiple curriculum locations helps to ensure that teachers will read these important content and pedagogical supports. Figure 8 is a section from the teacher guide that explains the data displayed in the marine gravity anomaly layer and highlights how to analyze the geospatial patterns displayed in the data. The gravity anomaly layer indicates different densities in the oceanic crust and continental crust. The layer provides a geospatial visualization to help learners understand how continental crust transitions to oceanic crust at a passive continental margin. The teacher guide highlights how to use the Continent Boundaries tool to illustrate how Bouger gravity anomalies are controlled by crustal densities in the passive margin transition zone.

Implementation

During the 2012-2013 school year, 12 Grade 8 Earth and space science middle-level teachers in four urban schools in the northeast region of the United States participated in this curriculum reform initiative. The teachers taught 1,124 students (ages 13-15) at all four middle-level schools in the same urban school district. The schools included students of varying degrees of socioeconomic status. Ethnic backgrounds varied by school, with one school containing a much higher percentage of Hispanic students (72.1%) than the other schools. The overall student population was 53.7% Caucasian, 31.3% Hispanic, 11.6% African American, 3.3% Asian, and 0.1% American Indian. Eighty-three students (7.4%) were classified as English language learners by the school district.

Seven teachers were male and five were female. The teachers had a wide range of teaching experiences, from a first-year science teacher to a teacher with 21 years of experience. Content area certifications and backgrounds varied and included general K-8 certifications, middle-level science certifications, and secondary-level science content area certifications. One teacher taught science to two classes composed only of English language learners, and one teacher taught one class composed of only special education students with individualized education programs.

- d. Next, students should click on the **Map Layers** tab in the toolbox menu, and activate the **Marine Gravity Anomaly** layer by clicking on the check box. Explain to students that this layer displays changes in gravity (a result of the properties that define continental vs. oceanic crust) as you move across the continental margin and transition from continental crust to oceanic crust. An **eotvos** is a measure of the gravitational force at that location. **Stronger gravitational forces** are represented by **red-yellow** color on the GIS. **Weaker gravitational forces** are represented by blue-green color. Differences in gravitational forces occur because continental crust and oceanic crust have different compositions and different densities. **Oceanic crust is more dense than continental crust.** Oceanic crust is composed mainly of basalt and continental crust is mainly composed of granite. **A change in gravity occurs across the continental margin because the density changes at the transition boundary between continental crust and oceanic crust.** This is indicated by locations on the map where **red/yellow** colors appear next to **blue/green** colors when the marine gravity anomaly layer is displayed.



- e. A change in gravity occurs across the continental margin because oceanic crust is composed of "mafic" minerals (such as basalt) that are denser than the "felsic" continental crust (such as granite). This is indicated by the color change on the map when the marine gravity anomaly layer is displayed. The biggest gravity anomaly occurs where there are transitions in crust type. This is along continental margins.
- f. To help see the boundary, instruct students to click on the **Continent Boundaries** tab in the toolbox menu. Click **"Add Boundaries"**. This button will trace the continental margin around North America and Africa with a thick black line. Students should clearly see the red-yellow color on the left side of the boundary and the blue color to the right of the boundary.

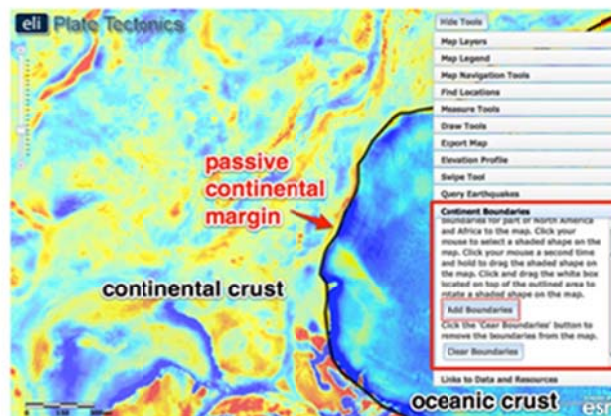


Figure 8. Section from the Investigation 4 teacher guide explaining the Bouguer gravity anomaly layer and the geospatial pattern this layer displays at the continental margin.

The teachers' prior experience using geospatial technologies in their classroom ranged from 0 to 5 years. Three of the teachers had pilot tested earlier versions of the Web GIS investigations in their classrooms during the previous school year. One of these teachers was a member of the curriculum development team. This year was the first that nine of the teachers implemented the tectonics investigations with their classes and used Web GIS as a learning technology for classroom instruction. The teachers were limited by their school district to receive only 11 hours of face-to-face professional development during 2 days prior to implementing the Web GIS investigations with their students.

The face-to-face professional development experiences were designed based on effective professional development strategies that foster curriculum implementation and included active learning experiences by teachers, the opportunity to collaborate with peers, the use of classroom-based instructional materials, the opportunity to reflect on teaching practice, and sufficient time to implement what has been learned (as in Garet et al., 2001; Penuel et al., 2007).

A primary focus of the professional development was on promoting geospatial thinking and reasoning skills. The face-to-face experiences included active learning experiences by the teachers (Penuel et al., 2009) with the new Web GIS investigations using the classroom-based instructional materials. The teachers completed the same investigations that their students were to complete during the school year. The teacher learning experiences focused on using the Web GIS to display, query, and analyze georeferenced tectonics data, and focusing on geospatial data analysis for making inferences about geospatial patterns and geospatial relationships. Pedagogical discussions during the sessions focused on how to explicitly model geospatial data exploration and analysis techniques and how to scaffold students' geospatial thinking and analysis skills with a focus on different strategies for students at different academic achievement levels.

During the face-to-face sessions, the teachers had opportunities to collaborate with their peers and discuss where the Web GIS investigations best fit within their district-approved tectonics unit. The face-to-face sessions also provided teachers with the opportunity to reflect on their teaching practices as they discussed which instructional practices would work best for students and which practices needed modification to accommodate specific learning needs of English language learners or students with learning disabilities. Teachers also received a 2-hour lecture and discussion by a university geologist that included up-to-date content information concerning tectonics, geodesy, and a contemporary understanding of geologic hazard forecasting.

Evidence of Effectiveness

We evaluated the effectiveness of the curriculum-linked professional development approach to support the science teachers' professional growth during the curriculum enactment of the Web GIS investigations using a postimplementation survey. A goal of our evaluation approach was to assess the effectiveness of both the curriculum materials and the Web-based curriculum support materials to promote the teachers' professional growth related to their geospatial science pedagogical content knowledge in addition to their science content knowledge.

The postimplementation survey included items derived from a related geospatial energy curriculum study (see Bodzin et al., 2012) that assessed how the curriculum support materials helped teachers grow professionally in their knowledge about geospatial

technologies, geospatial technology skills, and energy content knowledge. The survey items in that study were designed to assess the usefulness of the curriculum support materials to provide science pedagogical content knowledge for teaching with geospatial technologies in addition to sufficient energy content knowledge. We modified select items for our own evaluation purposes to focus specifically on how well the Web GIS tectonics curriculum materials and the teacher support materials promoted the teachers' tectonics content knowledge, geospatial thinking and reasoning skills, and understandings of how Web GIS could be used to promote science learning—each an important element of geospatial science pedagogical content knowledge.

Focus group interviews were also conducted with the teachers using a protocol that included items that focused on the effectiveness of the materials to support teacher enactment of the Web GIS investigations. The purpose of the focus group was to provide additional evaluation information about the affordances of the curriculum materials to provide enhanced geospatial pedagogical practices for student learning. The interviews were audiotaped and transcribed.

Responses from both the postimplementation survey and focus group interviews were analyzed for the teachers' perceived impact of the curriculum materials to support their pedagogical content knowledge related to teaching tectonics with Web GIS. The results indicated that the curriculum materials were effective in supporting the science teachers' professional growth during the curriculum enactment and supported their teaching of the Web GIS investigations.

Most teachers perceived that their tectonics content knowledge, geospatial thinking and reasoning skills, and understandings of how Web GIS can be used to promote science learning were enhanced as a direct result of their teaching with the curriculum (see Table 1). The majority of teachers noted that their tectonics content knowledge, geospatial thinking and reasoning skills, and understandings of how Web GIS can be used to promote science learning increased as a result of their use of the educative support materials provided in the curriculum (see Table 2).

The majority of teachers noted that both their science pedagogical content knowledge and geospatial pedagogical content knowledge increased as a direct result of their use of the curriculum and educative support materials (Table 3). The teacher support materials helped teachers to use the Web GIS with their students, provided pedagogical supports for the teachers to think about how to adapt their instructional practices to meet the needs of their students, and introduced them to ways of teaching Earth science with Web GIS. Eleven of 12 teachers acknowledged that the curriculum materials provided them with information to help their students explore and analyze geospatial data with the Web GIS.

In the focus groups, the teachers discussed how tectonics is a difficult science topic to teach using typical learning activities and that teaching and learning with Web GIS offered many benefits to their students. Many teachers commented that the Web GIS provided them with the ability to teach their students with a “more concrete way to understand abstract ideas.” The teachers discussed how the Web GIS assisted them in teaching their students to think more geographically. As one teacher commented, “Students are able to view locations and scientific data such as ocean depths and natural events that would not be visible in real life.”

Table 1Teacher Knowledge Gains During Implementation of Web GIS With Students ($n = 12$)

Item	Strongly Disagree % (<i>n</i>)	Disagree % (<i>n</i>)	No Opinion % (<i>n</i>)	Agree % (<i>n</i>)	Strongly Agree % (<i>n</i>)	Mean
My knowledge about Web GIS increased as I used the ELI Tectonics Web GIS investigations.	0.0% (0)	8.3% (1)	8.3% (1)	33.3% (4)	50.0% (6)	4.25
My geospatial thinking and reasoning skills increased as I used the ELI Tectonics Web GIS investigations.	0.0% (0)	8.3% (1)	8.3% (1)	50.0% (6)	33.3% (4)	4.08
My content knowledge about tectonics increased as I used the ELI Tectonics Web GIS investigation with my students.	0.0% (0)	16.7% (2)	8.3% (1)	41.7% (5)	33.3% (4)	3.92
My understanding of how Web GIS can be used to promote science learning increased as I used the ELI Web GIS investigations.	8.3% (1)	0.0% (0)	16.7% (2)	41.7% (5)	33.3% (4)	3.92
<i>Note.</i> Scale is 1 = <i>Strongly Disagree</i> to 5 = <i>Strongly Agree</i> .						

The teachers unanimously agreed that being able to analyze data in the Web GIS was a much better pedagogical approach than having to work with multiple side-by-side maps or worksheets. The teachers also discussed how the Web GIS provided for an active learning environment. One teacher offered the following comment that captured the opinion of the group: “Students are able to query and look to see what hazards are near them and what hazards they are likely to never encounter. The student is able to manipulate the map and be responsible for their own learning.”

In the postimplementation survey responses, the teachers described many ways that the Web GIS enhanced the way they typically taught tectonics concepts to their students. The majority of teachers ($n = 9$) commented that the Web GIS was “a great visualization tool” that could be manipulated to highlight connections and relationships among different Earth data layers. Five teachers noted that the use of the Web GIS visualizations enhanced their students’ understanding of concepts. One teacher stated that “the images on the computer provided the students with excellent visual imagery of concepts that otherwise would be much more difficult for a teacher to demonstrate.”

Three teachers explicitly mentioned that the Web GIS investigations provided them with the opportunity to teach certain tectonics concepts in much greater detail than they normally would have. For example, one teacher stated, “I previously would have only touched on the fact that you find small sections of the mid-ocean ridge that have horizontal fractures.” Another teacher stated, “This curriculum allowed students to participate and discover answers to questions that they may not have had in prior years.”

Table 2Teacher Knowledge Gains While Using Support Materials ($n = 12$)

Item	Strongly Disagree % (n)	Disagree % (n)	No Opinion % (n)	Agree % (n)	Strongly Agree % (n)	Mean
My knowledge about Web GIS increased as I used the support materials (Teachers Guide, videos) provided on the ELI Tectonics Web site.	0.0% (0)	0.0% (0)	8.3% (1)	75.0% (9)	16.7% (2)	4.08
My geospatial thinking and reasoning skills increased as I used the support materials (Teachers Guide, videos) provided on the ELI Tectonics Web site.	0.0% (0)	0.0% (0)	33.3% (4)	41.7% (5)	25.0% (3)	3.92
My content knowledge about tectonics increased as I used the support materials (Teachers Guide, videos, content background pages) provided on the ELI Tectonics Web site.	0.0% (0)	8.3% (1)	16.7% (2)	50.0% (6)	25.0% (3)	3.92
My understanding to how Web GIS can be used to promote science learning increased as I used the support materials (Teachers Guide, videos, content background pages) provided on the ELI Tectonics Web site.	0.0% (0)	0.0% (0)	16.7% (2)	50.0% (6)	33.3% (4)	4.17
<i>Note.</i> Scale is 1 = <i>Strongly Disagree</i> to 5 = <i>Strongly Agree</i> .						

Table 3

End of Tectonics Unit Implementation Survey Responses Pertaining to the Usefulness of Curriculum Support Materials ($n = 12$)

Item	Strongly Disagree % (n)	Disagree % (n)	No Opinion % (n)	Agree % (n)	Strongly Agree % (n)	Mean
The teacher support materials (teacher guides, content materials, FAQs) helped me to use the Web GIS with my students.	0.0% (0)	0.0% (0)	8.3% (1)	41.7% (5)	50.0% (6)	4.42
The curriculum materials provided me with information to help my students view, manipulate, and analyze rich data sets using the Web GIS.	0.0% (0)	8.3% (1)	0.0% (0)	66.7% (8)	25.0% (3)	4.08
The teacher support materials (teacher guides, content materials, videos) provided pedagogical supports for me to think about how I might adapt my instructional practices to meet the needs of my students.	0.0% (0)	8.3% (1)	25.0% (3)	8.3% (1)	58.3% (7)	4.17
The instructional materials (student handouts, assessment items) could easily be modified to address the needs of my students.	0.0% (0)	8.3% (1)	16.7% (2)	16.7% (2)	58.3% (7)	4.25
The teacher support materials (teacher guides, content materials, videos) introduced me to ways of teaching Earth science with Web GIS.	0.0% (0)	0.0% (0)	16.7% (2)	33.3% (4)	50.0% (6)	4.33

Note. Scale is 1 = *Strongly Disagree* to 5 = *Strongly Agree*.

Discussion

Many science teachers have not had sufficient professional development experiences that foster science pedagogical content knowledge to adopt and implement Web GIS in science classrooms to promote both science learning and the development of geospatial thinking and reasoning skills. In order for students to be successful using a Web GIS integrated curriculum, teachers must develop a certain level of geospatial science pedagogical content knowledge. They must have an understanding of the complex interplay between science pedagogical content knowledge and geospatial pedagogical content knowledge. It entails teaching science with appropriate pedagogical methods that take advantage using Web GIS to model geospatial data exploration and analysis techniques and using appropriate scaffolding to promote geospatial thinking and analysis skills with students.

Understanding which types of pedagogical implementation supports may help teachers more effectively implement pedagogical approaches to promote student geospatial thinking skills is important (Baker et. al, 2015). The implementation findings discussed in this paper provide evidence that the design of the tectonics curriculum and educative support materials were effective with this group of middle level science teachers to promote their professional growth to teach complex Earth science topics with Web GIS. The design of the curriculum and support materials were helpful in providing the teachers with pedagogical content knowledge to teach with Web GIS investigations to promote geospatial thinking and reasoning skills.

A key component of the curriculum-linked professional development approach was providing substantial tectonics content and pedagogical supports within the design of Web-based curriculum and teacher support materials. This approach takes into account that many school districts provide classroom teachers with limited face-to-face professional development time to learn new content knowledge and pedagogical approaches for teaching with geospatial technologies.

Many middle level science teachers in the U.S. have general K-8 certifications and middle-level science certifications. The teachers with these certifications may not have a solid foundation in Earth and environmental science content knowledge. Providing additional tectonics content support within the curriculum and support materials may be an important component of the curriculum-linked approach to assist teachers with implementing the tectonics investigations, especially for urban school districts that may have a higher teacher turnover rate. The inclusion of curriculum-linked professional development materials as part of a school district's adopted Web-based curriculum can also provide for a sustainable mechanism to support new teachers who will be teaching a new geospatially integrated curriculum for the first time.

The professional development approach described in this paper reduces some of the challenges that teachers face when compared to other professional development approaches that use Web GIS that are not directly curriculum linked. First, when professional development that focuses on the integration of Web GIS that does not have a direct curriculum-linked focus is used, georeferenced data related to specific concepts must be identified, validated, and placed into a Web GIS. Locating valid and reliable data for Earth science investigations takes significant time.

Second, existing Web GIS and that is freely available for teachers may not have a readily available suite of geospatial analysis tools that middle-level teachers can easily use without additional training. Thus, the design of the tectonics Web GIS interface in this project played an important part for teacher's adoption of the tectonics investigations. The interface was easy to use, the analysis tools did not require extensive training to use, and the initial data displays for each investigation helped to make geospatial patterns and relationships readily apparent.

Important components of effective professional development design were integrated into the limited face-to-face professional development sessions. These included active learning opportunities for the teachers (Penuel et al., 2009), opportunities to collaborate with other teachers in their school district, a focus on the implementation of specific curriculum materials that aligned to the school district's learning goals, the opportunity for teachers to reflect on their pedagogical practices, and the opportunity to learn and practice new geospatial technology skills in a supportive environment. With any new innovation to be adopted as part of a system reform effort, teachers need to understand and embrace how the new technology-integrated learning experiences will enhance the existing curriculum. The 11 hours of face-to-face professional development provided the

teachers with sufficient time to understand how the Web GIS tectonics investigations could be used to enhance the existing school district middle-level science curriculum.

A lead middle-level science teacher in the school district was part of the development team and took an active role during the face-to-face professional development sessions. This teacher's involvement was important in the project's success. First, the teacher helped to ensure curriculum coherence for the tectonics investigations with the school district's learning goals for the eighth-grade curriculum during the development of the Web GIS investigations. Second, the teacher had much experience using the tectonics investigations during the prototype and pilot testing of the investigations with students of different academic levels. During the face-to-face sessions, this teacher could speak to the other teachers from firsthand experiences about what worked well and what did not work well when teaching with the Web GIS investigations.

Conclusion

In this project, the teachers received only 2 days of face-to-face professional development prior to implementing the Web GIS investigations as part of their curriculum. Short training programs reflect the reality of many urban school districts that have limited resources available to provide their teachers with face-to-face professional development experiences. This project illustrates an effective approach for designing a Web GIS-integrated curriculum with educative curriculum materials that can be used to support the professional growth of teachers when face-to-face professional development time is limited. The designs of these support features can serve as a model to other science teacher educators and curriculum developers to help promote the teaching and learning of science with Web GIS and other geospatial technologies. Providing embedded professional development within curriculum materials is a necessary and transformative educational mechanism to counter professional development constraints that challenge teachers who adopt and implement reform-based science curriculum in urban school systems (Fishman, Marx, Best, & Tal, 2003).

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